The MIT/Marine Industry Collegium
Opportunity Brief #64

COMMERCIALIZATION

OF

AUTONOMOUS UNDERWATER VEHICLES

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Editor: John Moore Jr.

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Additional copies can be obtained from:

MIT Marine Industry Collegium
Building E38-308
292 Main Street
Cambridge, Massachusetts 02139

For workshop information, call John Moore Jr. TEL: (617) 253-4434
FAX: (617) 258-5730

TABLE OF CONTENTS

INTRODUCTION

MIT has always supported the notion that research and technology development can not occur in a vacuum. Therefore, MIT takes a very proactive approach to bringing both industry and government into the academic setting to inform them about current research developments and for academic researchers, to understand what these organizations' future needs will be. The MIT Sea Grant College Program (MITSG), through its Marine Industry Collegium Program, has adopted this approach wholeheartedly. Since the mid-seventies, MITSG has supported a wide variety of unmanned underwater vehicle (UUV) research programs. In conjunction with this research, the Collegium has provided a forum for the transfer of research findings to the marine community. The symposium which this Opportunity Brief describes is the fifteenth such Collegium sponsored program devoted to some aspect of UUV research and development.

This symposium departs to some extent from the traditional program format. Instead of having research presentations that focus on a specific area of UUV research and development, this symposium's presentations will focus on future commercial markets for intelligent autonomous underwater vehicles (AUVs). The convergence of two factors makes this symposium timely. First, there is significant downsizing in research support within the Department of Defense, a traditional and significant source of AUV research and development. Second, AUVs are beginning to show the reliability and robustness that commercial markets demand and the cost-effectiveness of using AUVs in certain applications is beginning to be demonstrated.

These two factors are encouraging AUV developers to actively pursue commercial markets. However, developers of AUVs will not see opportunities realized in these markets until they obtain a broader understanding of commercial market needs and the drivers of those needs.

By initiating a dialogue between the AUV development community and future commercial markets this symposium will explore those commercial markets that hold the most promise for this technology. The symposium will explore the opportunities, as well as the obstacles that exist, to the application and use of AUVs within the various commercial markets. Presentations and discussions will touch on a number of key issues relating to existing technologies used in marine markets and what these markets will demand in performance and cost requirements of AUVs to justify a switch from traditional techniques to this relatively new technology. The symposium will also have two panel discussions to further address the issues of whether or not AUV technology is ready for the commercial market and also whether or not a national policy is needed to pull this technology out of the defense market and into the commercial market.

In organizing this symposium we attempt to bring together the key players within the AUV development community and the marine commercial markets to foster the future development and use of this critical technology; a technology that has the potential to revolutionize how we study our marine enviroment.

John Moore Jr.
Symposium Chairman &
Collegium Director

SYMPOSIUM AGENDA

Commercialization of Autonomous Underwater Vehicles

January 25, 1994

8:00-8:30	REGISTRATION
8:30-8:50	Welcome and Introduction *John Sweeney, Draper Laboratory* *Don Perkins, National Research Council, Marine Board* *John Moore Jr., MIT Sea Grant College Program*
8:50-9:35	KEYNOTE SPEAKER: Autonomous Underwater Vehicles - Why? *Vick Hall, Vice President, SONSUB Services*
9:35-10:20	Design and Utilization of Small, High Performance Autonomous Underwater Vehilcles *James G. Bellingham, MIT Sea Grant College Program*
10:20-10:40	BREAK
10:40-11:25	The Use of Undersea Remotely Operated Vehicles in the Offshore Oil Industry *Drew Michel, ROV Technologies, Inc.*
11:25-12:10	Current Technologies Used and Future Needs for Ocean Survey Operations *Eric A. D. Swinney, John E. Chance & Associates*
12:10-1:00	LUNCH
1:00-1:45	Possible Uses of Autonomous Underwater Vehicles in Offshore Seismic Exploration *William J. Cafarelli, Halliburton Geophysical*
1:45-2:30	Applications of In-Situ Technologies in Fisheries Research and Autonomous Underwater Vehicle's Potential Role *Jack W. Jossi, NOAA, National Marine Fisheries Service, Narragansett Laboratory*
2:30-2:45	BREAK
2:45-3:30	Current and Future Technology Needs for NOAA's Hydrographic Survey Operations *Samuel P. De Bow, Jr., NOAA, Hydrographic Services Branch*
3:30-4:15	Preliminary Assessment of Autonomous Underwater Vehicles in Meeting National Data Needs *Hauke L. Kite-Powell, Woods Hole Oceanographic Institution*
4:15-5:00	PANEL DISCUSSION - Perceptions versus Reality: Are Autonomous Underwater Vehicles Ready for Commercial Markets? *Ken Collins, Applied Remote Technologies* *William H. Key, Jr., Klein Associates* *Drew Michel, ROV Technologies, Inc.* *William E. Shotts, U.S. Navy* *Dana R. Yoerger, Woods Hole Oceanographic Institution*
5:30-7:00	EVENING RECEPTION *MIT Faculty Club*

Commercialization of Autonomous Underwater Vehicles

January 26, 1994

8:00-8:30	LATE REGISTRATION
8:30-8:35	Introduction to Second Day *John Moore Jr., MIT Sea Grant College Program*
8:35-9:20	The Role of Autonomous Underwater Vehicles in Marine Science Research into the 21st Century *Daniel J. Fornari, Woods Hole Oceanographic Institution*
9:20-10:05	Seafloor Monitoring Requirements of a Major Dredged Material Disposal Project offshore New Jersey *Scott E. McDowell, SAIC*
10:05-10:20	BREAK
10:20-11:05	Searching for the Cable Break, Can Autonomous Underwater Vehicles Help? *Tom Smith, AT&T*
11:05-12:00	PANEL DISCUSSION - Do We Need an Industrial Policy for Autonomous Underwater Vehicle Commercialization? *Dick Bloomquist, Naval Surface Warfare Center* *James Ferguson, International Submarine Engineering* *Larry L. Gentry, Lockheed Missiles & Space Company* *Hauke L. Kite-Powell, Woods Hole Oceanographic Institution* *Mack D. O'Brien, Jr., Draper Laboratory*
12:00	ADJOURN

SYNOPSES OF PRESENTATIONS

January 25

8:50
KEYNOTE SPEAKER: Autonomous Underwater Vehicles - Why?
Mr. Vic Hall, Vice President, SONSUB Services

Over the duration of this symposium, many excellent papers are to be presented, highlighting current and future trends in the development of autonomous underwater vehicles (AUVs) and offering various fields in which AUV technology could be applicable.

Like so many of today's emerging technologies, AUV development was primarily developed for the defense market. However, with the so-called break-out of peace and subsequent slashing of defense spending, the scientific and commercial markets are now being targeted as potential users/market for AUVs.

The scientific community may, I feel, be prepared to embrace AUVs in one form or another as an ideal platform for wandering around the ocean depths in a pre-programmed way, gathering valuable data for later research and analysis.

The marine commercial market is not nearly so accommodating. This market tends to be very conservative in its approach to such new or emerging technologies. The idea of casting a valuable asset over the side of a vessel without a substantial piece of string attached to it is the stuff nightmares are made of. At some time or other, most of us involved in the commercial Remotely Operated Vehicle (ROV) market have experienced an unscheduled AUV type excursion, much to the consternation of our insurers.

The reaction to AUVs in the marine commercial sector, particularly the Oil & Gas Industry, will be -- Why?

Why is AUV technology needed when the industry is presently well served by ROVs? It has been suggested that AUVs are ideally suited to subsea pipeline and trunkline survey, providing visual and positional information and being launched in "set & forget" mode from a vessel smaller and more cost effective than that required to support standard ROV operations. This appeared to be the ideal opportunity to introduce AUVs, but the development of intelligent pigging systems, based on proven procedures and technology, which travel inside the pipeline and are capable of gathering several streams of data are now being viewed as the ideal pipeline survey tool. This particular example is typical of the prevailing attitude in today's Oil & Gas industry. The preference is to adapt or modify existing systems to accept new advances that enhance and improve efficiency and performance. New or advanced technology will only be utilized if it can be positively shown to be more cost effective than that which already exists. Once you overcome the "Why?", the next hurdle is "How much is it going to cost?"

There is definitely a potential market for AUV technology in today's offshore Oil & Gas industry. The strong message that contractors are receiving however is that cost, not technology is the driving consideration in future development projects. As long as demand for hydrocarbon products remain soft, the number of potential producing fields that are considered economically "marginal" will increase. This is leading the quest for a "cheaper mouse trap" rather than a "better" one.

The challenge facing emerging and new technologies such as AUVs is how to adapt to market conditions and create the opportunity necessary to introduce such a technology into the marine commercial market. It can be done, but not without the assistance and co-operation of the players already involved.

9:35

Design and Utilization of Small, High Performance Autonomous Underwater Vehicles
Dr. James G. Bellingham, Massachusetts Institute of Technology, Sea Grant College Program

For five years the MIT Sea Grant Underwater Vehicles Laboratory has been focusing on the development of small, high performance AUVs. In this talk I will review the motivations for imposing size and weight constraints, the resulting advantages achieved, and operational schemes that fully exploit the vehicle characteristics. Experience of the Sea Grant AUV team will be reviewed in the design, construction and operation of the Sea Squirt, Odyssey, and Odyssey II vehicles.

Small AUVs, here defined as vehicles weighing less than 300 kilograms, have the potential to provide economical access to the ocean. The primary advantage of small size is the potential for low cost fabrication and operational support. In particular, small vehicles can be operated off of smaller ships, in rougher seas, and constructed through a variety of manufacturing techniques that are not available for larger vehicles. Furthermore, small vehicles can be designed and constructed for greater maneuverability and robustness to collisions. MIT Sea Grant has constructed a prototype of this class of vehicle, the *Odyssey.* The vehicle has operated since summer of 1992 in the vicinity of Boston and in open water tests off of the coast of Antarctica. *Odyssey II* an improved versions of *Odyssey,* is presently being readied for tests in the Arctic in spring of 1994.

Disadvantages of small size are reduced range and payload capacity. However, with careful design, ranges in excess of 1000 kilometers are possible today. Achieving such performance requires a low drag vehicle with efficient propulsion, and electronics that consume a minimum of power. The power constraint is a particular problem for sensor systems. At present there are relatively few sensor systems available that are adaptable for use in an AUV, and even fewer which are small and low power.

Realization of the full benefits afforded by small high performance vehicles requires new operational modes be developed. An intermediate step is to employ AUVs as compliments to existing oceanographic assets. As vehicle reliability is improved, AUVs will provide oceanographic vessels with the capability to increase their "deep-tow" effectiveness many times over through the operation of several AUVs simultaneously. Operations semi-independent of an oceanographic vessel pose a more ambitious use of AUVs. Here the vehicle would be launched and recovered by the ship, but not attended during the mission.

This mode of operation might compliment manned submersible or ROV operations. Operations of AUVs independent of surface vessels could be accomplished with vehicles launched from shore. Perhaps the most exciting operational scheme is afforded by the Autonomous Ocean Sampling Network (AOSN)* concept, in which moored buoys provide power and communication nodes thus providing a long term, multiple vehicle presence in the ocean.

The potential benefits derived through the use of AUVs is exciting, however realization of these benefits requires a user community. At MIT Sea Grant we have chosen to focus our initial efforts on the scientific community, to obtain scientific data with AUVs under conditions that either preclude or make economically unacceptable the use of traditional techniques. To this end, we are presently focusing on under-ice and deep ocean survey missions. Arctic operations of *Odyssey* are scheduled for March and April of 1994, and deep water operations on the Juan de Fuca Ridge (off the Oregon coast) and the East Pacific Rise are scheduled for late 1994. The operational experience and the resulting vehicle refinements that can be expected should lead to a demonstrated capability which we intend to transition to commercial applications.

10:40

The Use of Undersea Remotely Operated Vehicles in the Offshore Oil Industry
Mr. Drew Michel, ROV Technologies Inc.

The underwater intervention and observation tasks performed by divers, manned submersibles and remotely operated vehicles (ROVs) in this industry are basic inspection and construction tasks similar to those in drilling and construction activities on land.

Divers performed these tasks during the first 25 years of offshore oil operations. Atmospheric diving suits and manned submersibles were used for a short time beginning in the late sixties. While still popular in the scientific community, their use is not prevalent in the offshore oil industry at this time. Safety issues and inefficiency of these earlier technologies fueled the research that resulted in development of ROV systems that now dominate underwater observation and intervention in the offshore oil industry.

Since the most common underwater tasks are observation and inspection, it follows that the most common class of ROVs* is the small observation, or light work, vehicle. Approximately 700 vehicles of this class are reported in service. The majority of these systems however, do not have the capabilities required for offshore oil industry use. They are either underpowered or have no tether management system. Less than 200 of these systems are active within the offshore industry.

Most offshore operators outfit these relatively small ROV systems with black and white and color video cameras, a still camera, a scanning sonar, and one small manipulator. The vehicle operates from a handling system that includes an underwater tether management system (TMS). These systems are widely used for platform and pipeline inspection and for construction support.

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* Curtin, T.B., Bellingham, J.G., Catipovic, J. & Webb, D., **Autonomous Oceanographic Sampling Networks**, *Oceanography*, accepted for publication, 1993.

The ROV system of choice in the offshore oil industry is the work class, or heavy work class vehicle. These vehicles use 50 to 100 hydraulic horse power, providing up to 1,000 pounds of forward thrust. They are typically equipped with low light level black and white (SIT) and wide angle color video cameras. Most use a high resolution color sonar and gyro compass for navigation. The manipulator suite normally is a five function "grabber" arm and a seven-function spatially correspondent manipulator capable of lifting 200 pounds. Approximately 200 of these large work class ROVs are reported in service at this time. One hundred and sixty of those are engaged in offshore oil operations. The largest percentage of use for work class systems, in terms of total days offshore is in drill rig support. Construction and repair support and pipeline inspection make up the remainder of their task uses offshore.

The industry is entering an era where the ROV will be the primary tool on construction and repair projects in water depths to 6,000 feet. Development work is in progress that will result in deepwater pipeline and subsea tree repairs on the sea floor. To accomplish this work, remote underwater intervention capabilities must be increased. Technologies like force feedback manipulators, stereo video and ultra-high resolution sonar must be improved.

The next quantum step is to eliminate the tether, something that terrifies conservative offshore operators. There is an opportunity for the use of autonomous underwater vehicles in the recent movement toward the development of lower cost subsea field development efforts.

11:25
Current Technologies Used and Future Needs for Ocean Survey Operations
Mr. Eric A. D. Swinney, John E. Chance & Associates

With the ever growing demand for increased precision in offshore survey operations, it has long been apparent that the removal of the sensors from the survey vessel would contribute to this increase in precision. This has led to a myriad of sensor carriers ranging from manned submersibles, ROVs, remotely operated towed vehicles (ROTVs), passive towed bodies to dragged sleds. These technologies will be reviewed citing the type of work they are most commonly engaged in and what typical sensor packages are carried. The required support vessel and crew will also be reviewed to provide a comparative costing of these systems.

Two work areas shall be reviewed in detail. These work areas are the most obvious for the application of AUVs at this time.

The first area is that of deep water (300ft+) surveys for cable routes, pipelines and drilling sites. The comparative advantages and limitations of hull mounted vs. towed swath bathymetry will be discussed. These advantages and limitations will include accuracies achieved, positioning problems, operational weather windows, logistical considerations and some typical productivity figures and costs. Within this context the characteristics of the ideal AUV will be defined and also the budgetary constraints that must be met in order to make the AUV commercially viable.

This financial analysis will be performed on each of the three main survey-work types: the cable route, the pipeline route, and the drilling sites. Assumed increases in productivity or cost savings will be used, along with historical and projected utilizations, to attempt to identify a price that industry would be willing to pay for an AUV that would meet the technical needs mentioned earlier.

The second area covered in detail during this presentation is that of pipeline inspection. The review will commence with defining the various requirements of pipeline inspections such as position, definition of freespans, depth of burial, visual, out of straightness, CP, trench profile, etc. The individual or groups of sensors that can meet these requirements will be discussed along with any limitations or special needs regarding the sensor carrier that are required. The discussion will then proceed to descriptions of typical sensor carriers such as towed bodies, ROVs, ROTVs, sleds and divers. The discussion will focus on comparative advantages and disadvantages of each type reviewing such parameters as technical validity, sensor payload, operating environment, weather limitations and, of course, productivity and cost. As in the earlier case, an attempt will be made to substitute an ROV with an AUV in the pipeline inspection scenario and by so doing attempt to define the operating parameters of such an AUV. Mention will also be made of emerging technologies that may totally or partially negate the need for external pipeline inspections.

The paper will conclude by identifying some of the requirements needed before AUVs can become commercially viable. They will have to present greatly enhanced data quality, improve production, lower support costs and lastly come with the correct price tag.

1:00

Possible Uses of Autonomous Underwater Vehicles in Offshore Seismic Exploration
Mr. William J. Cafarelli, Halliburton Geophysical Services, Inc.

Exploration in offshore provinces is performed with a variety of seismic acquisition systems. The most commonly used today are the marine streamer, the single group recorder (radio telemetry), and the ocean bottom cable. Each system will be described in brief, but this presentation will focus on ocean bottom cable operations, where applications of AUVs are most apparent. Several tasks will be described in which the use of AUVs might be suitable. Reference will be made to other seismic acquisition systems where appropriate.

In three dimensional (3D) ocean bottom cable seismic recording, one or more cables are deployed on the ocean bottom, where they remain stationary. The cable contains the seismic sensors, or groups, at regular intervals. Each group contains an array of particle velocity sensitive gimballed geophones and pressure sensitive hydrophones. The recording vessel anchors, connects to the cables, and checks the electrical integrity of the cables and sensor groups. During recording, the source vessel, towing only an airgun array, shoots a series of lines. Upon completion, the cables are retrieved and redeployed ('rolled') and the process repeated until the survey is complete. 'Swath' and 'patch' shooting will be described.

Presently, accurate dual sensor combinations require the acquisition of 'calibration' data. A separate pass is made by the shooting vessel over the cable and a single airgun fired above each group. The angle between the source and group should be within 45 degrees of vertical. For instance, for a six meter source depth and 66 meter group depth, this means the source must fire within 60 meters of the group in the horizontal plane. However, for a 16 meter group depth this means it must fire within ten meters of the group, which may be well beyond the navigating ability of a skilled captain even in calm seas. Consequently, the 'calibration' data acquired in shallow water areas is often compromised.

This task could be performed by an AUV with a mounted airgun that follows the cable, detects the groups, and fires over them. More specifically, the AUV would be required to travel at a constant depth of approximately six meters with a uniform speed of at least five knots and maintain its position within ten meters of each group. The AUV's location must be known to within five meters. An accurate clock, synched to the recording system clock, is also required on the AUV. Upon firing, the time and location of the AUV is recorded for telemetry back to the recording vessel, not necessary in real time. On the recording vessel, the seismic recording instruments are programmed to initiate recording in a window prior to the firing time, based upon the predetermined, constant AUV speed.

Location of the sensor groups on the ocean bottom is typically performed by recording two lines parallel to, but on different sides of, the cable. Ranges from the four closest shots to each group are computed, allowing for the computation of the least-squared-error position of that group. With minor modification, the AUV as described above could perform this task. In this case, the AUV's path would be offset from the cable by a distance roughly equivalent to the group interval, often 50 meters. Providing the AUV can be directed to fire at a precise starting point and maintain a constant speed, the groups need not be detected by the AUV. The AUV could simply travel a straight path, firing the gun adjacent to each group at the predicted time based upon the assumption of constant velocity and a straight travel path. Obviously, there is the potential for the AUV to locate the groups directly, thus providing the redundant system that is often desired. This would be applicable to single group recorder (radio telemetry) systems as well.

Jumpers are used along the cable to service the line, and at line ends to connect one line to another. Floating Norwegian buoys or submersible, acoustically activated 'pop-up' buoys are often attached to these jumpers. Norwegian buoys create obstacles and drift, pulling the groups away from the preplanned positions. "Pop-up" buoys don't 'pop-up' with great regularity. AUVs could be used to replace most buoys. When accessing a particular jumper, the AUV would be sent to locate the rope attached to the cable, grasp the rope, and surface with it. A minimum acceptable speed for this might be ten knots.

When a multimillion dollar ocean bottom cable or marine streamer is severed or otherwise lost on the sea floor, an intense effort is undertaken to locate and retrieve it. At times, the crew can retrieve the cable by blindly grappling for it. More often than not, a sidescan sonar locates the missing cable and divers retrieve it. This task could be performed in exactly the same way as a jumper is retrieved. Obviously, the AUV must have enough thrust to surface with the cable if there is no rope attached. Lacking that, simply locating the cable is an important task.

These tasks illustrate potential uses of AUVs in offshore seismic exploration. Estimates will be made of potential cost savings that could be expected through the use of AUVs. Time permitting, other potential uses may be evaluated such as running jumpers and coupling the groups to the ocean bottom.

1:45

Applications of In-Situ Technologies in Fisheries Research and the Autonomous Underwater Vehicle's Potential Role

Mr. Jack W. Jossi, National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Narragansett Laboratory

Not available at time of publication.

2:45

Current and Future Technology Needs for NOAA's Hydrographic Survey Operations

Lieutenant Commander Samuel P. De Bow, Jr., National Oceanographic and Atmospheric Administration, Systems Support Section, Hydrographic Surveys Branch

The National Oceanic and Atmospheric Administration (NOAA), within the Department of Commerce, has a statutory mandate "to provide charts and related information for the safe navigation of marine and air commerce, and to provide basic data for engineering and scientific purposes and for other commercial and industrial needs" (33 U.S.C. 883). NOAA can trace its lineage back to the creation of the United States Coast Survey in 1807 by Thomas Jefferson, which later became the Coast and Geodetic Survey (C&GS), and now resides within the National Ocean Service (NOS) in NOAA. Since that time over 10,000 near-shore surveys that make up a suite of over 1000 NOAA nautical charts have been conducted.

The types of instrumentation presently used by NOS for shallow-water hydrographic surveys from small platforms are vertical-beam depth sounders, with one or two independent beams, and conventional side-scan sonar. In areas where 100% area coverage is required, conventional unfocused side-scan sonar systems are utilized. This operation constrains the vessel to speeds of 1.5 - 3 meters per second (3 - 6 knots). When hazards to surface navigation are detected by side-scan, the least depth and location are determined by divers, or single beam echo sounders with reduced line spacing to insure 100% echo sounder coverage. Both methods are time consuming and labor intensive. Thus, the allowable speeds and line spacing associated with this small-platform survey operation cause shallow-water surveys to be inefficient when compared to state-of-the-art swath technology available today.

Productivity figures of merit differ widely between individual surveys. Each individual survey is planned to contain the number of lineal and square nautical miles required for hydrographic sheet completion. Since a chart may be a compilation of many hydrographic surveys, sheet completion is of paramount concern. Factors that have a direct impact on productivity are: survey scale, survey platform, survey methods (hydrography or side-scan sonar), amount of maritime traffic while surveying, existing environmental conditions, bottom topography, amount of fish pots, and purpose of the survey. Normally, a complete hydrographic survey includes basic soundings, positions of all navigational aids, positions and least depths on wrecks, rocks, obstructions, positions of landmarks, and verification of shoreline features in accordance with published standards of the International Hydrographic Organization. Adverse weather conditions are a severe debilitating factor affecting both survey quality and productivity.

NOAA's limited charting experience with AUVs was as a joint participant with the Naval Research Lab to conduct a test and evaluation of the DOLPHIN/EM100 system in August 1992. The test concluded that a DOLPHIN was rather unwieldy and did not allow the option of conducting remote surveys as frequently conducted with standard hydrographic survey launches. However, the platform had the advantage of stability in rough seas and the capability of running 24 hours a day, thus eliminating the "personnel" requirement to staff and rotate launch crews.

NOAA is in the process of revitalizing its aging oceanographic and hydrographic fleet through the Fleet Replacement and Modernization (FRAM) program. As part of this program, NOAA envisions an upgrade to existing survey ships and launches that do not preclude future use of AUVs. The upgrade will ensure that survey operations are conducted by acquiring hydrographic soundings, reconnaissance bathymetry, and side-scan sonar imagery simultaneously with swath systems over as wide a swath as possible. In this mode, detailed soundings for chart application will be acquired while depth anomalies between survey lines are detected, thereby improving the quality and quantity of hydrographic operations. In the near future, airborne laser hydrographic systems are expected to provide adequate survey coverage in many nearshore areas in depths up to 10 meters. NOAA, however, will continue to need a portable, quick response system that can isolate and determine the least depth and position on previously unknown hazards to surface navigation.

3:30
Preliminary Assessment of Autonomous Underwater Vehicle's Potential in Meeting National Data Needs
Dr. Hauke L. Kite-Powell, Woods Hole Oceanographic Institution, Marine Policy Center

AUVs are potentially cost-effective alternatives to traditional platforms for certain marine data acquisition missions. The work described here is a preliminary effort to define the "universe" of U.S. national marine data acquisition needs in terms that make it possible to identify missions for which AUVs may be economically attractive. By indicating the most promising applications and directions for AUVs in marine data acquisition for the coming decades, the results of this work should be useful in prioritizing AUV research and development activities and in guiding AUV commercialization efforts.

Many government agencies (including NOAA, USGS, MMS, and EPA), private firms, and academic institutions collect data in the marine environment for a variety of uses ranging from nautical charting and minerals development to ocean circulation studies and fisheries management. The data collected through these efforts is classified according to parameters useful to the selection of sensor platforms. Possible parameters include depth range, distance from shore support facilities, sensor weight, spatial and temporal density, "real-time criticality," and accuracy requirements for both the measurement itself and associated depth/position. By making assumptions about changing priorities in ocean activities, it is possible to anticipate how the present mix of ocean data needs may evolve over the coming decades.

Ocean data are collected using a variety of more or less traditional collection platforms, including surface ships, ROVs, submersibles, divers, moored buoys, drifters, airplanes, and satellites. AUVs, with its own particular strengths and weaknesses, represent an addition to this list of platforms. By comparing the performance parameters (range, payload, navigation, cost) of AUVs and other platforms in the context of the universe of data acquisition requirements, it is possible to identify the types of data acquisition missions for which AUVs (versus other platforms) are likely to offer the most cost-effective alternative.

The information derived from this mapping of platform capabilities with data acquisition needs can help identify AUV research priorities by highlighting the factors limiting AUV performance in the most relevant data collection missions. It can also assist commercialization efforts by focusing AUV design efforts for those missions in which AUVs are likely to be more cost-effective than alternative platforms.

4:15
PANEL DISCUSSION - Perceptions Versus Reality: Are Autonomous Underwater Vehicles Ready for Commercial Markets?
Mr. Ken Collins, Applied Remote Technologies
Mr. William H. Key, Jr., Klein Associates
Mr. Drew Michel, ROV Technologies, Inc.
Capt. William E. Shotts, U.S. Navy
Dr. Dana R. Yoerger, Woods Hole Oceanographic Institution

The two questions which the panel members will address are as follows:

1. Have AUVs demonstrated sufficient reliability, robustness, and utility for acceptance by commercial markets? Give examples to support your position.

2. What key factors/issues does the AUV community need to address to successfully introduce this technology to commercial markets?

January 26

8:35
The Role of Autonomous Underwater Vehicles in Marine Science Research into the 21st Century
Dr. Daniel J. Fornari, Woods Hole Oceanographic Institution, Geology & Geophysics Department, & Deep Submergence Laboratory

Traditionally, marine science research programs conducted at the continental shelf edge to the depths of the abyss have relied on tethered instruments that either transmit data over an armored cable, or record the data using a self-contained logging system. In addition to those systems, shallow and deep-water manned submersibles have provided the ability to make field observations and collect samples in situ; often a critical perspective that is necessary to solve particular process oriented problems in the geological, biological and chemical oceanographic disciplines. More recently, ROVs using fiber optic cables have significantly expanded the resolution and bandwidth of information acquired by instrumentation at or proximal to the sea floor. Just as ROVs have revolutionized the installation and maintenance of various subsea industrial systems, they have the potential to revolutionize marine scientist research on many levels.

Autonomous underwater vehicles have a similar potential to significantly impact the quality, diversity and quantity of measurements that ocean scientists can make at various levels in the oceans. Because of the ability of AUVs to operate independently of a dedicated support vessel, and their capacity to make measurements over long time periods (weeks to months), AUV-based research represents a methodology that offers many advantages to scientists wishing to gain a time-series perspective on chemical, biological and geological processes occurring in the water column and on the sea floor in various environments. The developing AUV technology and engineering efforts taking place during the 1990s must pay close attention to the specific needs of the multidisciplinary oceanographic community if AUVs are to become accepted and widely used scientific tools in the 21st century. Embedded within the technology development must be close collaboration between AUV developers and scientists, and dedicated efforts to educate the science users in how best to integrate AUVs into their research programs and utilize AUVs to produce the best quality data and most cost-effective scientific research.

AUVs must have the ability to navigate accurately on the seafloor using either traditional, long-baseline bottom-moored transponders, or navigation benchmarks and doppler sonar if over very long distances. Other navigation techniques, including coming close to the surface and interrogating GPS satellites at various intervals, may be required if the AUV is to traverse large areas of the ocean. A few of the critical scientific sensors that must be integrated into AUVs if they are to be useful for a wide variety of oceanographers are: conductivity/temperature/depth (CTD) recorders, transmissometers, chemical sensing arrays, low-light level electronic-still or video cameras and lighting (strobes or flood lights), laser scaling in photographic data, precision altitude and depth sensors, and acoustic modems for transmitting data to surface ships or fixed buoys and sending control instructions to the AUV to modify its mission parameters.

9:20

Seafloor Monitoring Requirements of a Major Dredged Material Disposal Project Offshore New Jersey

Dr. Scott E. McDowell, Science Applications International Corporation

Under a dredging/disposal permit granted by the U.S. Army Corps of Engineers - New York District (COE), the Port Authority of New York/New Jersey dredged approximately 465,000 cubic yards of contaminated sediments from the Port of Newark/Elizabeth during the summer of 1993. Because the dredged sediments contained trace (parts per trillion) levels of the toxic contaminant dioxin, there is great concern over the potential effects on the marine environment due to dredging and ocean disposal of this material. Environmentalists and the coastal population are concerned because this material was disposed of at the existing Mud Dump Site, located 6 nautical miles offshore New Jersey. Dredged material has been dumped continuously at this site since 1914, but with the increased environmental concern about potential transport of contaminants into the food chain, the Port Authority was required to cover ("cap") the dredged material mound with at least 1 meter of relatively clean sand. This capping operation was conducted from July to December 1993.

The U.S. Environmental Protection Agency (EPA) and the COE developed a Monitoring and Management Plan (M&MP) for the Dioxin Capping Project. Under this plan, SAIC conducted numerous field surveys to obtain environmental data and information to: (1) establish a local environmental baseline prior to disposal of dredged material, (2) direct and monitor the disposal and capping operations, (3) assess the engineering effectiveness of the cap (e.g., its resistance to erosion during winter storms), and (4) evaluate the long-term effectiveness of the cap for preventing the transport of contaminants into the overlying sediments, benthos, and water column.

Field monitoring activities for the M&MP began in November 1992 and will continue into mid-1994, with over 15 independent surveys conducted. Monitoring techniques include high-resolution bathymetric surveying, REMOTS sediment profile photography, chemical analysis of sediment and tissue samples, geotechnical analysis of core samples, subbottom profiling of sediment characteristics for three dimensional mapping of mound features, and moored current/wave measurements. Although these techniques and technologies represent the state-of-the-art for shipboard monitoring, it may someday be possible to substitute AUV-based measurements for the more conventional, vessel-based survey techniques. To identify potential (future) applications of AUV technology for dredged material disposal monitoring projects, the technical merits and cost effectiveness of the existing vessel-based monitoring techniques will be assessed.

10:20
Searching for the Cable Break, Can Autonomous Underwater Vehicles Help?
Mr. Tom Smith, AT&T

Not available at time of publication.

PANEL DISCUSSION - Do we Need an Industrial Policy for AUV Commercialization?
Mr. Dick Bloomquist, Naval Surface Warfare Center
Mr. James Ferguson, International Submarine Engineering
Mr. Larry L. Gentry, Lockheed Missiles & Space Company
Dr. Hauke L. Kite-Powell, Woods Hole Oceanographic Institution
Mr. Mack D. O'Brien, Jr., Draper Laboratory

The three questions whicn the members of this panel will address are as follows:

1. How effective has government support of AUV development been in developing AUVs to meet commercial market needs?

2. Are market forces enough to drive the future commercialization of AUVs? Give examples to support your position.

3. Will countries (or consortiums of countries, i.e. the E.C.) with significant industrial policies to support AUV commercialization, pose a significant threat to U.S. efforts in this field?

James Ferguson of the Canadian company ISE will answer the following question, instead of question one listed above:
Does Canada have a policy to support the commercialization of AUVs? If so briefly describe them.

BIOGRAPHIES OF PRESENTERS

Dr. James G. Bellingham
MIT Sea Grant College Program

Dr. Bellingham is laboratory manager of the Underwater Vehicles Laboratory at the MIT Sea Grant College Program, where he has been affiliated since 1989. His research interests include underwater navigation and the design and development of inexpensive, robust autonomous underwater vehicles to perform tasks in ocean exploration such as surveying, sampling, and inspection.

Dr. Bellingham received his S.B., S.M., and Ph.D. degrees in physics, all from M.I.T. He is a member of the Deep Submergence Science Committee, the American Physical Society, and the Executive Board, NE Section, of the Marine Technology Society.

Mr. Richard Bloomquist
Naval Surface Warfare Center

Not available at time of printing.

Mr. William J. Cafarelli
Halliburton Energy Services

Mr. Cafarelli is a geophysicist with the ocean bottom cable (OBC) division of Halliburton Energy Services, where he has been affiliated since 1982. His work includes the design of three dimensional surveys, developing data acquisition technical specifications, providing technical support for OBC crews in areas such as dual sensor calibration and on-board binning.

Mr. Cafarelli has a B.A. in mathematics from Boston College and is working towards his graduate degree in applied physics at the University of New Orleans. He was elected contributing member of Halliburton Geophysical Services technical staff in 1989, and holds memberships with the Society of Exploration Geophysicists and the Southeastern Geophysical Society.

Mr. Kenneth Collins
Applied Remote Technology

Mr. Collins is program manager and business area manager for unmanned underwater vehicle (UUV) research and development at Applied Remote Technology (ART). His responsibilities include project planning, technical performance evaluation, and directing proposal activity related to new UUV projects. He has conceived various innovative proposals for launching and recovering UUVs and was recently granted a patent in this area. Prior to joining ART in 1986, he developed advanced undersea vehicle systems for the Naval Ocean Systems Center in San Diego. Mr. Collins has comprehensive experience in new business development, management, engineering, construction, and at-sea testing of undersea viewing and vehicle systems for commercial and naval applications.

Mr. Collins holds B.A. and B.S. degrees in applied sciences and mechanical engineering from Lehigh University and an M.S. degree (abt) in ocean engineering from the University of Miami.

Lt. Commander Samuel P. De Bow, Jr.
National Oceanic & Atmospheric Administration, Hydrographic Surveys Branch

Mr. De Bow is a Lieutenant Commander and Chief of the Hydrographic Surveys Branch Systems Support Section at the National Oceanic & Atmospheric Administration. He is currently coordinating issues relating to existing shipboard hydrographic data acquisition and processing systems with particular emphasis on the development of new shallow water swath hydrographic systems and modifications to existing systems. He has been a commissioned officer with the NOAA since 1976, except for an interruption between 1990-1992, when he spent two years as manager of hydrographic surveys at Ocean Surveys, Inc. (OSI), in Connecticut.

Mr. De Bow received a B.S. in engineering management from Drexel University and an M.S. in hydrographic sciences from the Naval Postgraduate School in Monterey.

Mr. James Ferguson
International Submarine Engineering

Mr. Ferguson joined International Submarine Engineering (ISE) in 1981 and is currently vice president for development of ISE Research. At ISE, he has overseen the development of a number of programs including the Autonomous Remote Controlled Submersible and DOLPHIN, a high-speed radio controlled submersible. Prior to joining ISE, Mr. Ferguson served with the Royal Canadian Navy and rose to the rank of Lieutenant Commander before resigning his commission to join ISE.

Mr. Ferguson attended LeCollege Militaire Royal at St. Jean where he studied economics and political science.

Dr. Daniel J. Fornari
Woods Hole Oceanographic Institution, Geology and Geophysics Department, Deep Submergence Laboratory

Dr. Fornari joined the Geology and Geophysics Department at the Woods Hole Oceanographic Institution (WHOI) in 1993 as associate scientist and at the same time received appointment as chief scientist within WHOI's Deep Submergence Laboratory. Previously, he was affiliated with the Lamont-Doherty Geological Observatory of Columbia University for several years. His research interests include: morphology and structure of submarine volcanoes and submarine canyons; ocean floor tectonics; marine geophysical data; geochemistry and petrology of ocean floor rocks; seamounts; and deep and shallow-water submersible diving in various seafloor terrains. He has over 45 months of at-sea experience on all classes of oceanographic research vessels, and is experienced in the development of remote-sensing geophysical recordings and remote deep sea-camera data.

Dr. Fornari holds a B.S. in geology from the University of Wisconsin-Madison, and received his M.A. and Ph.D. degrees in marine geology from Columbia University. He serves on many scientific panels and committees, including the Deep Submergence Science Committee and the U.S. Science Advisory Committee.

Mr. Larry L. Gentry
Lockheed Missiles and Space Company, Inc., Marine Systems Group

Mr. Gentry is program manager for underwater vehicles in the Marine Systems Group of Lockheed. Since 1983, he has managed a number of underwater vehicle (UV) development programs at Lockheed. Mr. Gentry has supervised R&D projects for UVs including autonomous command and control, acoustic and optic communications, advanced structural materials, and precision inertial navigation. Formerly, he was involved in the development and installation of subsea oil and gas production systems.

Mr. Gentry has a B.S. in electrical engineering from Oregon State University and an M.S. in electrical engineering from San Jose State University. He is a past member of the U.S. National Research Council's Marine Board.

Mr. N.V. (Vick) Hall
SONSUB Services

Mr. Hall is a founding member of the SONSUB Group of companies (founded in 1987) and currently serves as vice president with responsibilities for development and new technologies. Mr. Hall first became involved in the subsea industry in 1975 and has served in a variety of positions from project engineer to regional manager for a leading world underwater contractor with activities primarily involved in Europe and Africa.

Mr. Hall, a native of Australia, received a B.S. in mechanical engineering.

Mr. Jack W. Jossi
NOAA, National Marine Fisheries Service, Narragansett Laboratory

Not available at time of printing.

Mr. William Hunter Key, Jr.
Klein Associates, Inc.

Mr. Key is the President of Klein Associates Inc., a company that designs and manufactures side-scan sonars. Prior to joining Klein, he worked in engineering sales for Digicourse, Inc., a manufacturer of heading sensors for undersea applications. Mr. Klein also served nine years as an officer with the U.S. Navy.

Mr. Key has a degree in marine engineering from the U.S. Naval Academy and an S.M. in naval architecture and marine engineering from MIT.

Dr. Hauke L. Kite-Powell
Woods Hole Oceanographic Institution, Marine Policy Center

Dr. Kite-Powell is a research associate at the WHOI Marine Policy Center. In addition to his responsibilities at WHOI, he is also a consultant to Cambridge Technology Partners and is an associate of the Woods Hole Research Consortium. Dr. Kite-Powell's current research interests are in technology policy, research and development management, and analysis of marine technology industries.

Dr. Kite-Powell received a B.S. in naval architecture and marine engineering, M.S. degrees both in ocean systems management and in technology and policy, and a Ph.D. in ocean systems management, all from M.I.T.

Dr. Scott E. McDowell
Science Applications International Corporation

Dr. McDowell is senior physical oceanographer for SAIC and has recently overseen the Dioxin Capping Monitoring Program at the New York Mud Dump Site. Prior to this project, he was lead oceanographer for EPA's extensive monitoring program at the 106-mile deep water dump site offshore New York. Previous to SAIC, Dr. McDowell developed the physical oceanography department at Battelle Ocean Services.

Dr. McDowell received a B.S. in chemical engineering from the University of Lowell, an M.S. in physical oceanography from the University of Michigan and a Ph.D. in physical oceanography from the University of Rhode Island. From 1992-1993, he served as chairman of the New England Section of the Marine Technology Society.

Mr. Drew Michel
ROV Technologies, Inc.

Mr. Michel founded ROV Technologies in 1986 and has engineers on full-time contract to Shell, Amoco and other major companies involved in the offshore petroleum industry. Mr. Michel has more than 27 years of technical and management experience in the marine electronics industry.

Mr. Michel is a senior member of IEEE, chairman of the Marine Technology Society's ROV committee and serves on the board of directors for both the Association of Diving Contractors and the Institute of Diving.

Mr. Mack D. O'Brien, Jr.
Draper Laboratory, Ocean Systems

Mr. O'Brien is currently Director of Ocean Systems at Draper Laboratory. He is actively involved with the development of unmanned undersea vehicles, submarine design support, design of the Seawolf ship control fault-tolerant computer, and support of the Navy's deep submergence systems. Prior to joining Draper, he worked for General Electric and Raytheon supporting the Fleet Ballistic Missile and Apollo projects. Mr. O'Brien first began working on underseas systems 26 years ago when he joined MIT's Instrumentation Laboratory shortly after graduating from college.

Mr. O'Brien has a B.S. in electrical engineering from Yale University.

Capt. William Shotts
U.S. Navy

Capt. Shotts joined the Navy in 1968 and qualified in submarines in 1971. From 1979 through 1984, he served in a variety of positions including two commands. Upon graduation in 1988 from the Defense Acquisition University's Program Management Course, Capt. Shotts was assigned program manager for unmanned undersea vehicles developments of the Defense Advanced Research Projects Agency (DARPA). Currently, he is the Navy's acquisition program manager for unmanned undersea vehicles.

Capt. Shotts received a B.S. degree from the University of Chicago and an M.B.A. from Marymount University.

Mr. Thomas Smith
AT&T

Not available at time of printing.

Mr. Eric A. D. Swinney
John E. Chance & Associates, Inc.

Mr. Swinney has been affiliated with John E. Chance & Associates since 1988. As Commercial Director, he is involved in all major construction projects in water deeper than 1000', utilizing medium, high and extra high frequency acoustic systems and pressure based high accuracy bathymetric systems. Previously he served as Chief Surveyor at OII, a division of Oceaneering, where he oversaw innovations such as the first GPS controlled rig move, the development of EHF acoustic systems for spool piece measurement, and the development of an ROV for survey operations.

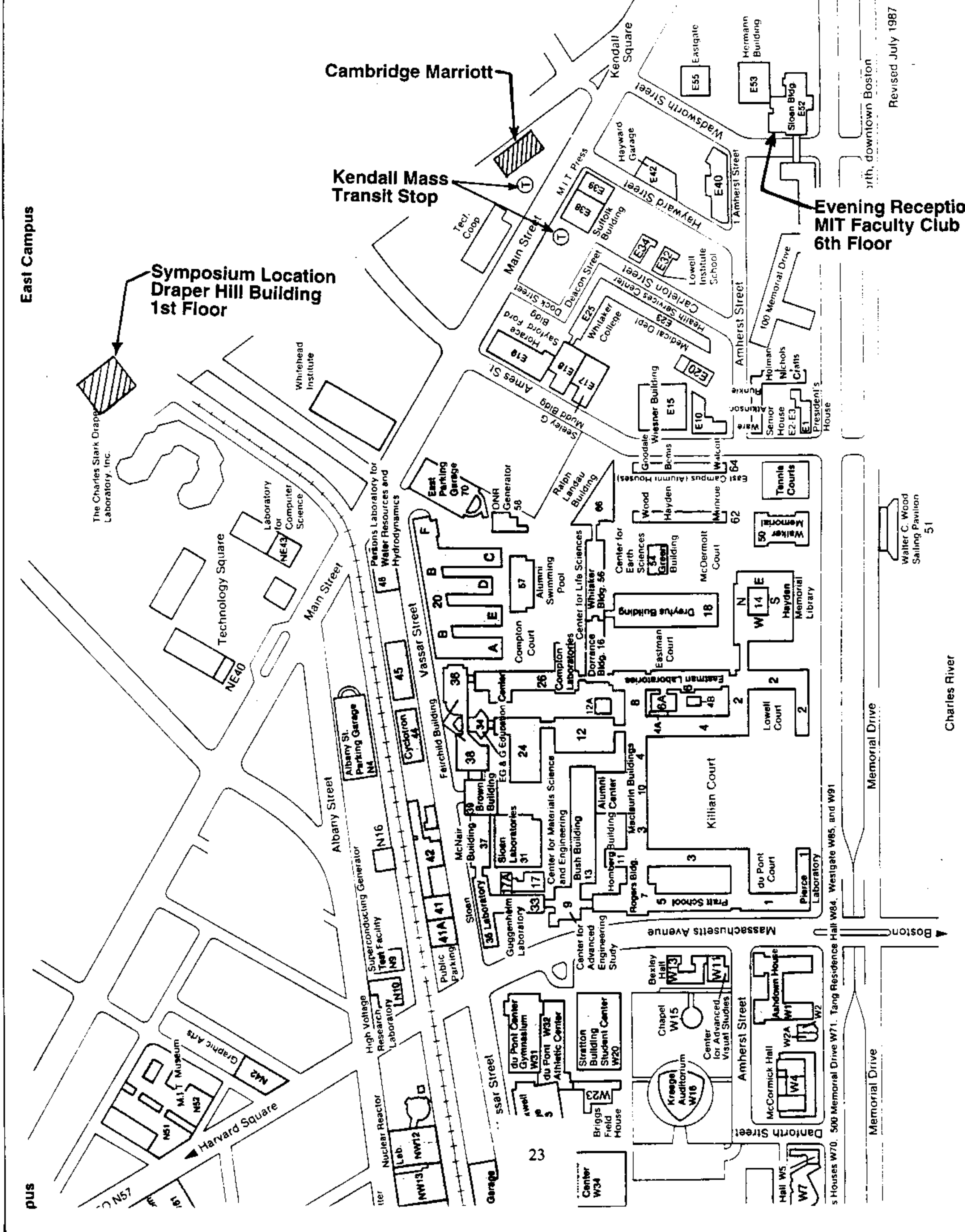
Mr. Swinney has a B.S. in geography from Portsmouth Polytechnic. He holds memberships in the Royal Charter Institute of Chartered Surveyors (Probationer), the Institute of Navigation, and the Hydrographic Society.

Dr. Dana R. Yoerger
Woods Hole Oceanographic Institution, Department of Applied Ocean Physics and Engineering, Deep Submergence Laboratory.

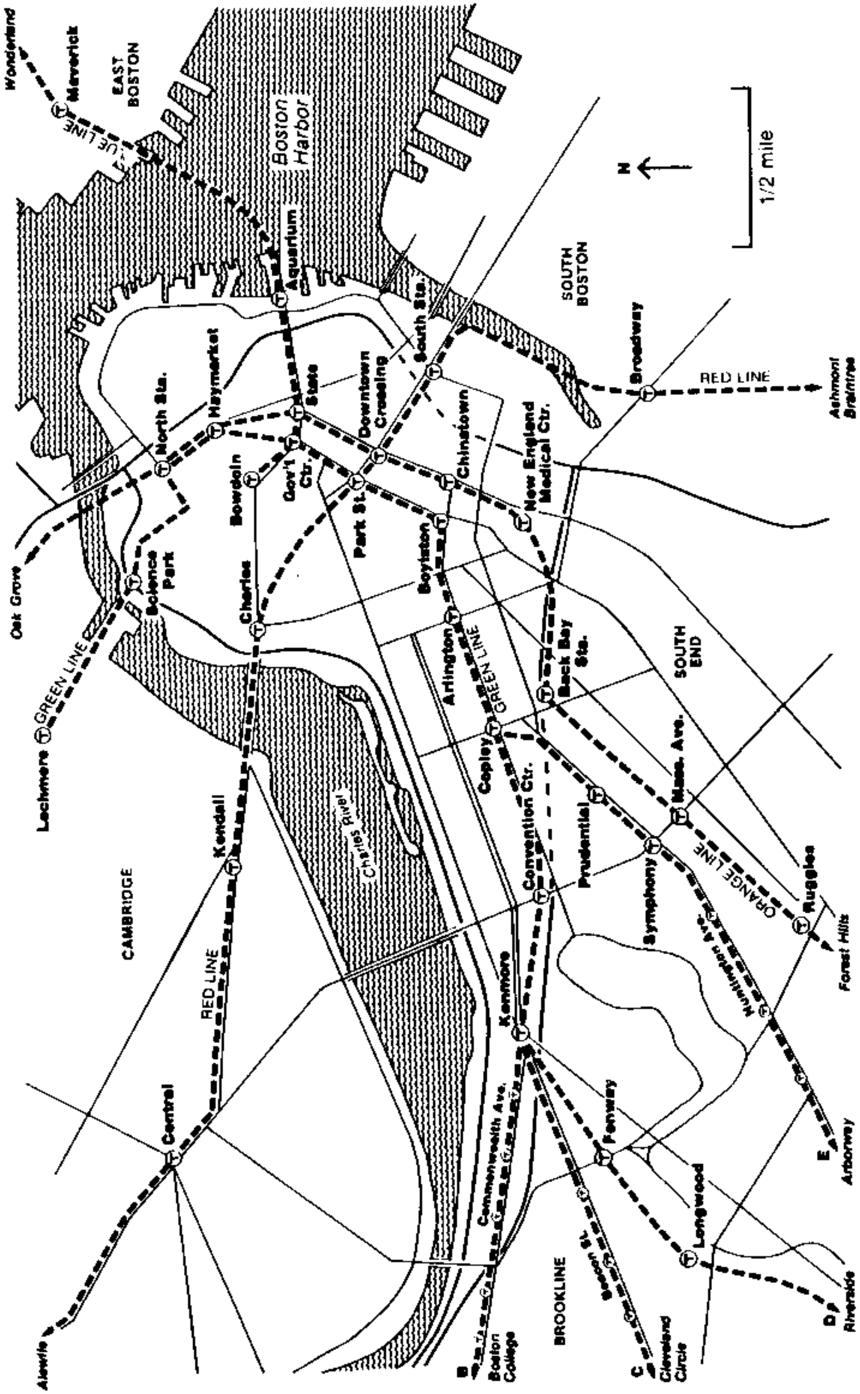
Dr. Yoerger has been with WHOI since 1983, most recently as an associate scientist in the Deep Submergence Laboratory. His current research interests involve the design, dynamics and control of underwater vehicle and manipulator systems. Dr. Yoerger has worked extensively with Dr. Robert Ballard of WHOI on deep sea robotics systems for the Jason Project.

Dr. Yoerger received his S.B., S.M. and Ph.D. degrees in mechanical engineering, all from MIT.

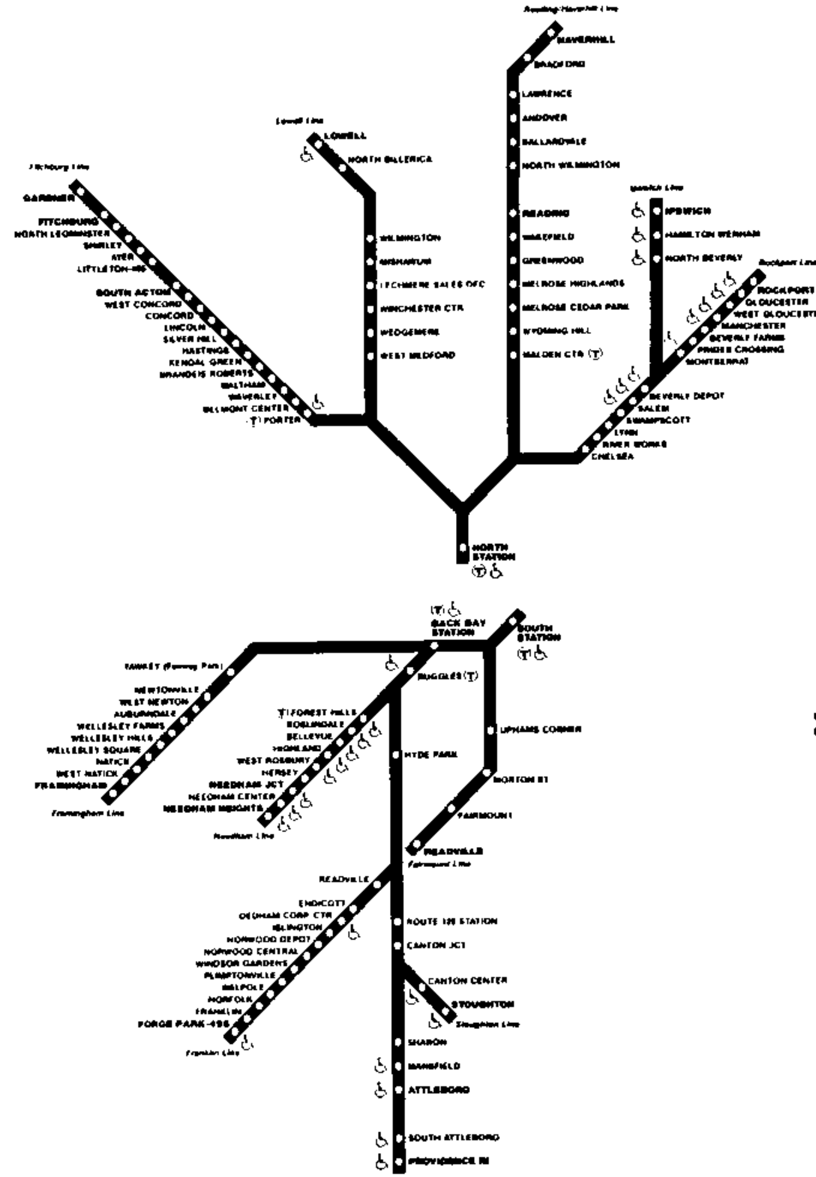
MAP OF MIT CAMPUS



Mass Transit for Boston/Cambridge

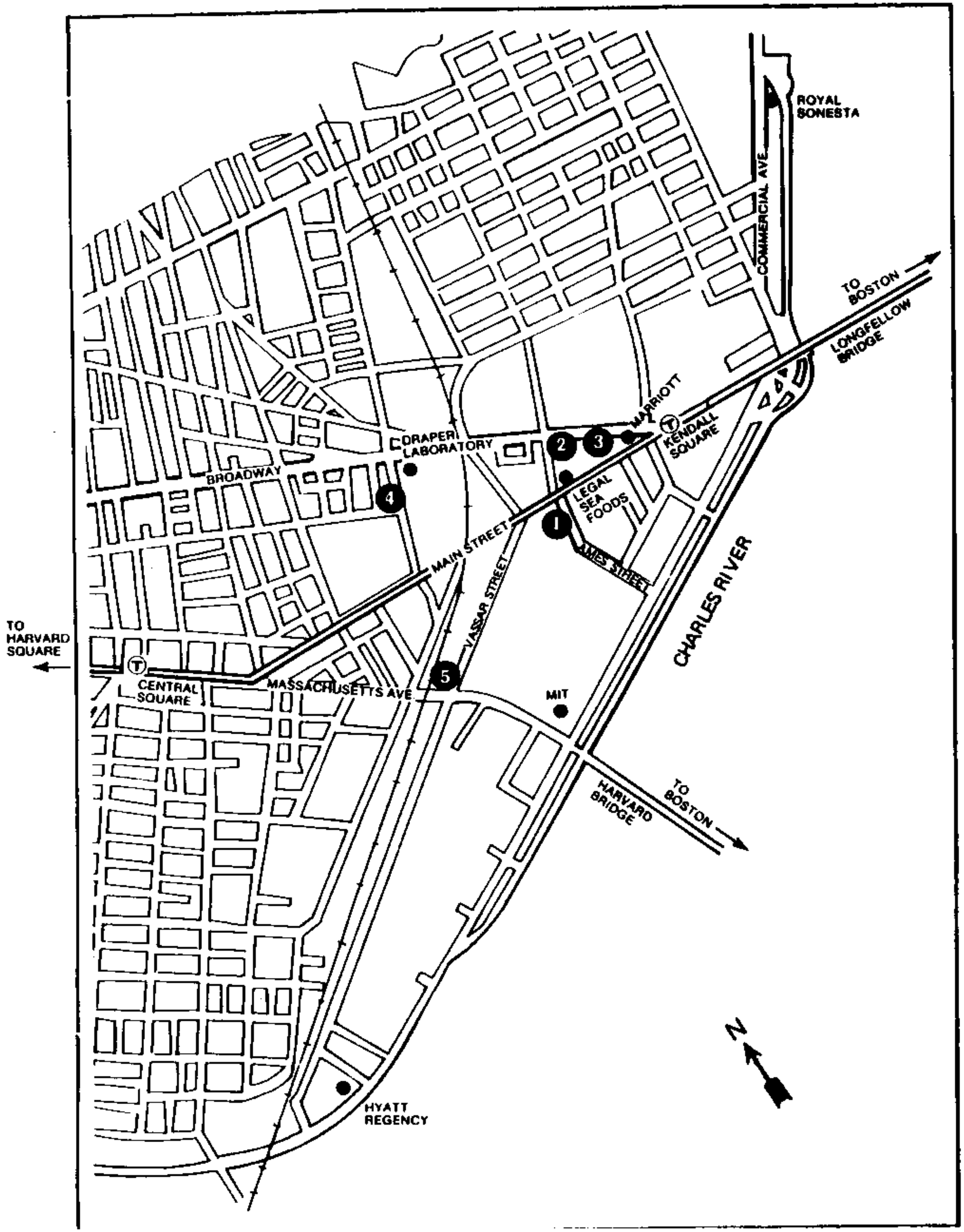


Commuter Rail System



Ⓣ Commuter Rail-Rapid Transit Connections

Green Line	**NORTH STATION**
Orange Line	**MALDEN CTR.** (Reading/Haverhill Line) **NORTH STATION** **BACK BAY STATION** **RUGGLES** (Needham, Franklin, Attleboro, and Stoughton Lines) **FOREST HILLS** (Needham Line)
Red Line	**PORTER** (Fitchburg Line) **SOUTH STATION**



Kendall Square Vicinity Parking

1. ~~Ames Street Lot~~
   ~~Ames and Main Street~~
   ~~225-0847~~

2. Cambridge Center Garage
   5 Cambridge Center
   Broadway and Ames Street
   (off of Main St., next to Legal Sea Foods)
   492-1956

3. Cambridge Center Marriott Hotel
   2 Cambridge Center (Valet parking)
   494-6600

4. ~~Polaroid Parking Garage~~
   ~~Adjacent to Draper Employee Garage~~
   ~~Technology Square~~

5. ~~Vassar Street Lot~~
   ~~Vassar St. and Massachusetts Ave.~~
   ~~(next to BayBank Automated Teller machine)~~

NOTE:
There is limited Draper Lab visitor parking available.
Many area hotels provide shuttle service to Draper Lab.

ACCOMMODATIONS*

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1-800-228-9290
617-494-6600

Royal Sonesta Hotel
5 Cambridge Parkway
Cambridge, MA 02139
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617-491-3600

Hyatt Regency
Memorial Drive
Cambridge, MA 02142
1-800-233-1234
617-492-1234

Howard Johnson
777 Memorial Drive
Cambridge, MA 02142
1-800-654-2000
617-492-7777

*Listed in descending order of proximity to symposium location.